Improving aerosol representation in NU-WRF in support of the emerging GEO-LEO satellite observation of air quality

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Acknowledgement

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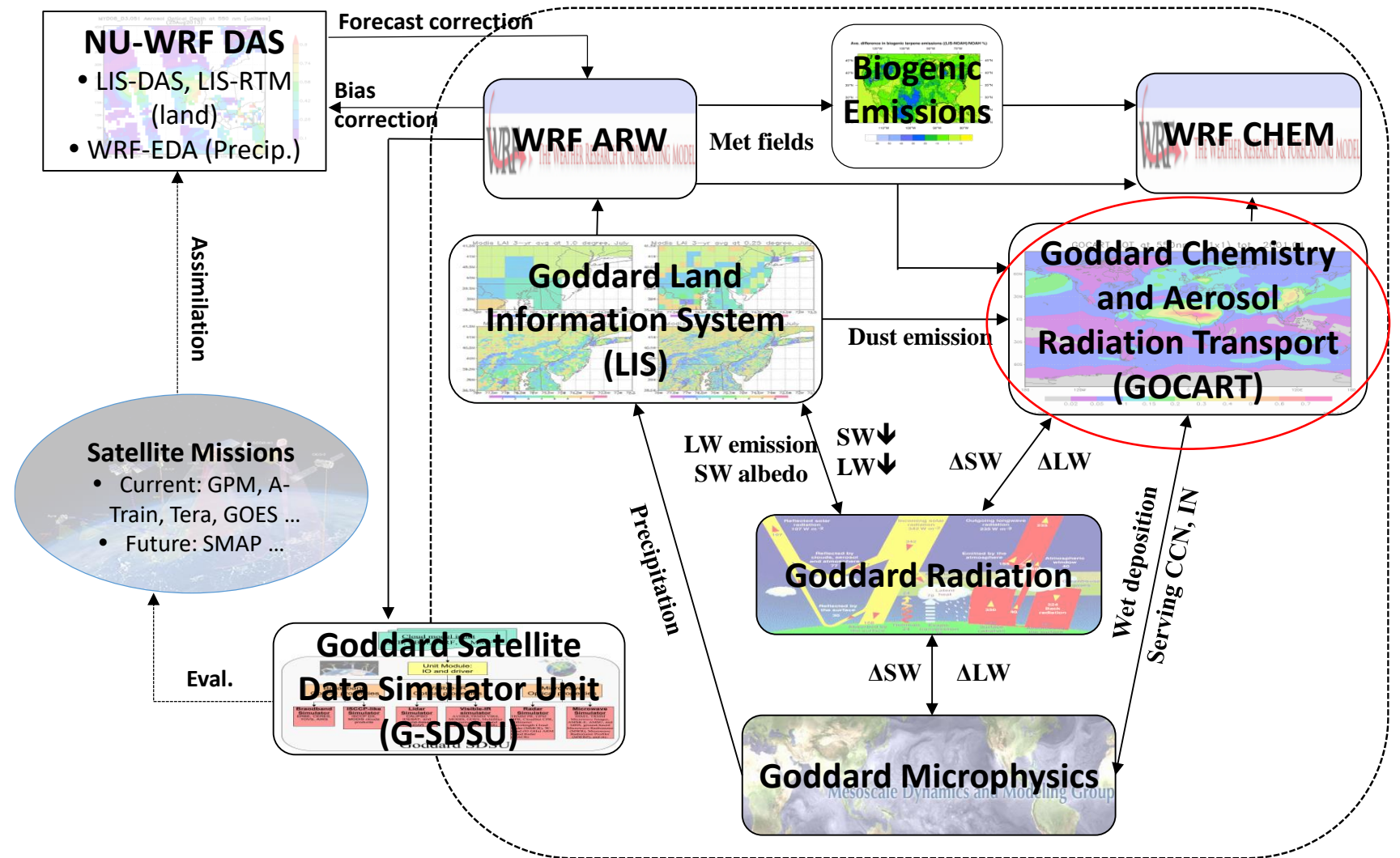
Background

1) The GEO-LEO space observing system provides new opportunities in measuring atmospheric composition at higher temporal resolution – valuable to understanding of diurnal pollution evolution, dust/wildfire plume transport, pollution-weather interactions

2) Numerical models are indispensable for integration and analysis of collected data

3) NASA model portfolio: GEOS-5, GISS Model E, and NASA Unified WRF (NU-WRF)
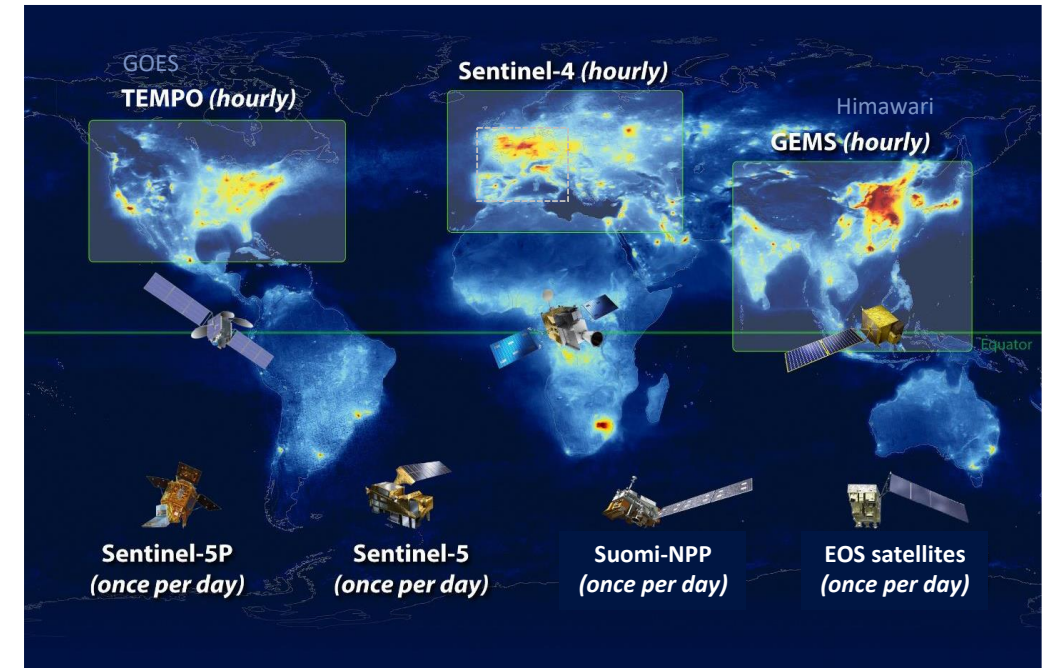
The emerging geostationary satellite constellation (GEMS, TEMPO, Sentinel-4) and complementary GEO and LEO satellites. Adapted from CEOS (2019) with modification. (Shaded areas are GEO-AQ viewing area.)

What separate NU-WRF from community WRF?

a) Superset of community WRF

b) Connect to GEOS-5/ MERRA-2 & MINDS: IC/LBC and GOCART background

c) GOCART, a bulk aerosol module, simple, effective, and computational efficiency

d) GOCART lacks functionality of nitrate aerosol simulation

NU-WRF DAS
- LIS-DAS, LIS-RTM (land)
- WRF-EDA (Precip.)

WRF ARW

Biogenic Emissions

WRF CHEM

Forecast correction

Bias correction

Met fields

Assimilation

Satellite Missions
- Current: GPM, A-Train, Tera, GOES …
- Future: SMAP …

Goddard Land Information System (LIS)

Goddard Chemistry and Aerosol Radiation Transport (GOCART)

Dust emission

Eval.

Goddard Satellite Data Simulator Unit (G-SDSU)

Precipitation

LW emission SW albedo

SW↓ LW↓

ΔSW ΔLW

Wet deposition Serving CCN, IN

Goddard Radiation

ΔSW ΔLW

Goddard Microphysics

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Update GOCART aerosols (consistent with the one in GEOS-5)

- Implement Secondary Organic Aerosol (SOA) parameterization

    1) AVOC (g) = 0.069 * A-EMISco

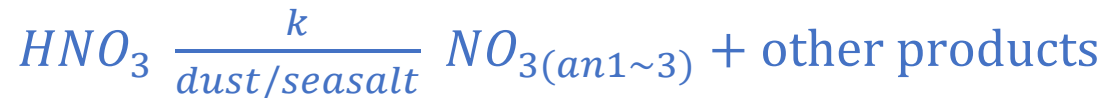   2) BBVOC (g) = 0.013 * BB-EMISco   *Hodzic & Jimenez, GMD, 2011*

    3) AVOC/BBVOC + OH $\longrightarrow$ SOA + other products   *Kim et al., ACP, 2015*

- Add nitrate

    1) solve for SO_4/NO_3/NH_3/H_2O system based on equilibrium thermodynamics
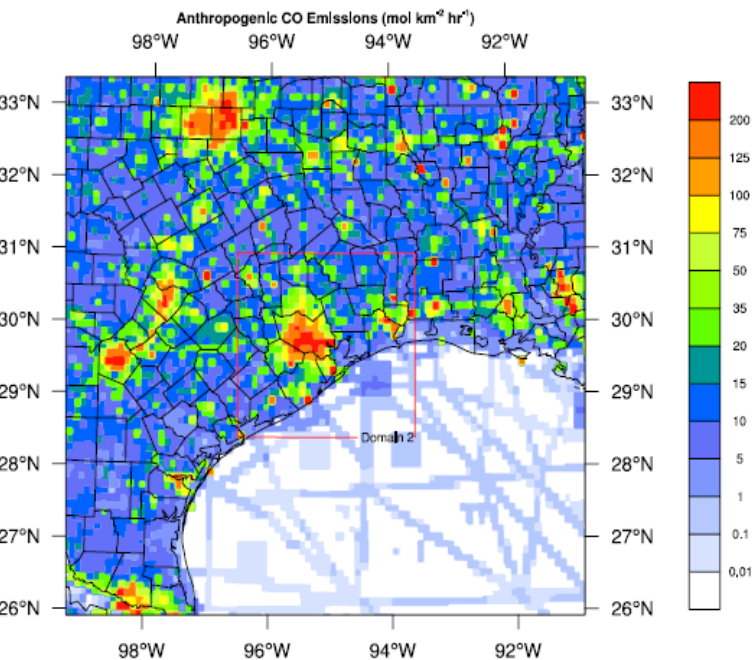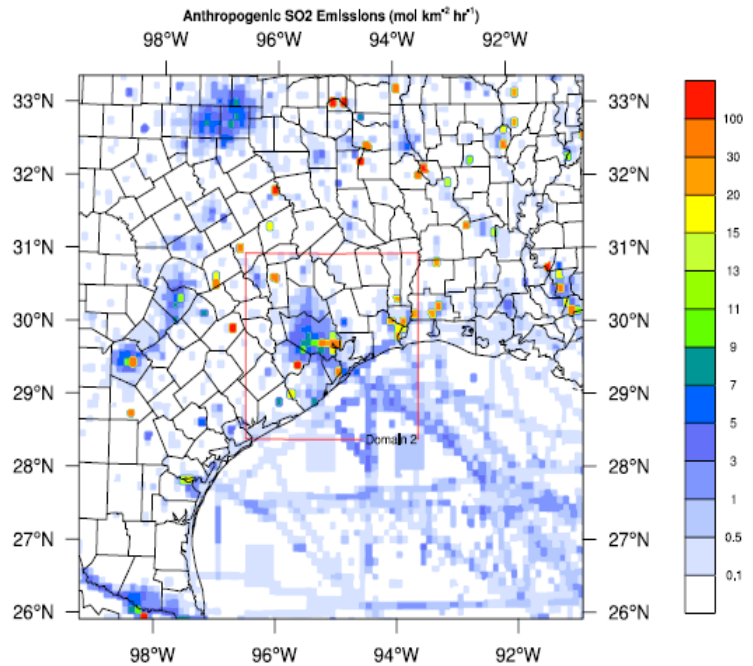
    2) nitrate heterogeneous reaction

    $$HNO_3 \xrightarrow[dust/seasalt]{k} NO_{3(an1\sim3)} + \text{other products}$$ *Bian et al., ACP, 2017*

- Aerosol removal processes

    dry deposition, settling, wet deposition (large scale or microphysics wet scavenging, and convective or cumulus wet scavenging)

Anthropogenic SO2 Emissions (mol km⁻² hr⁻¹)

Anthropogenic NH3 Emissions (mol km⁻² hr⁻¹)

Anthropogenic CO Emissions (mol km⁻² hr⁻¹)

Anthropogenic Aerosol Emissions (ug m⁻² s⁻¹)

NU-WRF configuration

- Microphysics: Goddard 4-ice

- SW/LW: Goddard

- PBL scheme: MYJ

- Surface layer: Monin-Obukhov

- Land surface: Noah

- Urban canopy: Single-layer

- Chem/Aerosol: RADM2-GOCART

- Emissions: CEDS/GFEDv4s/MEGAN2
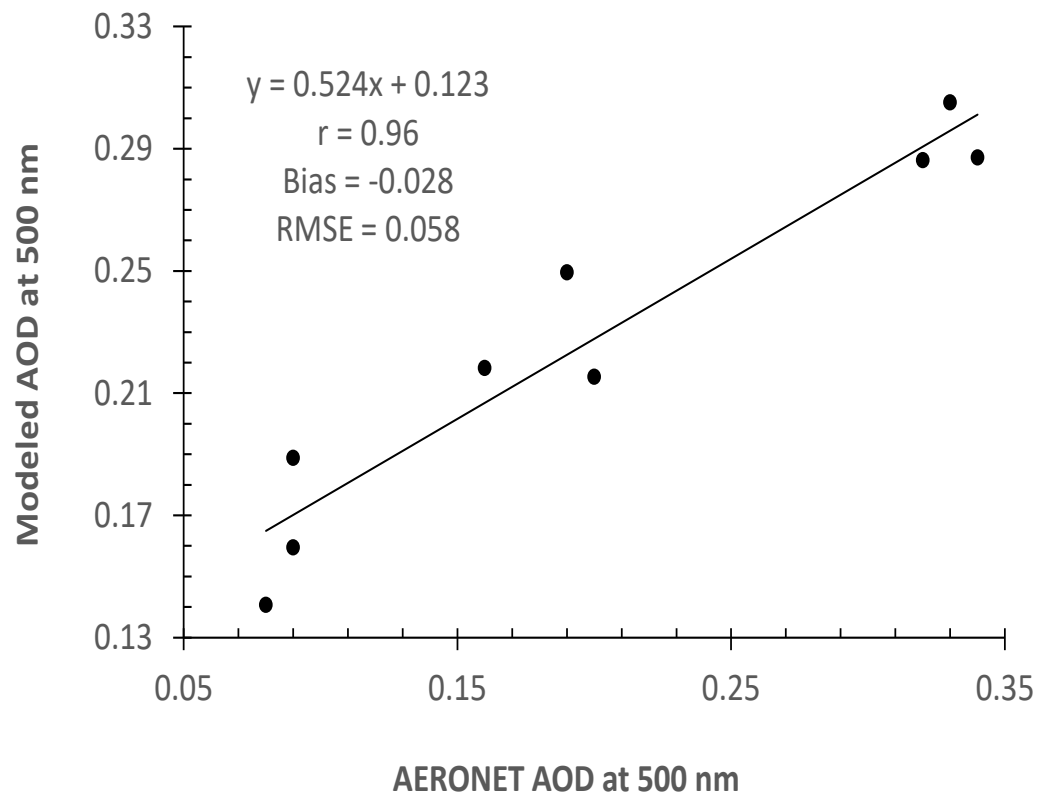
- Resolutions: 3/1 km with 40 vertical layers up to 10,000 HPa

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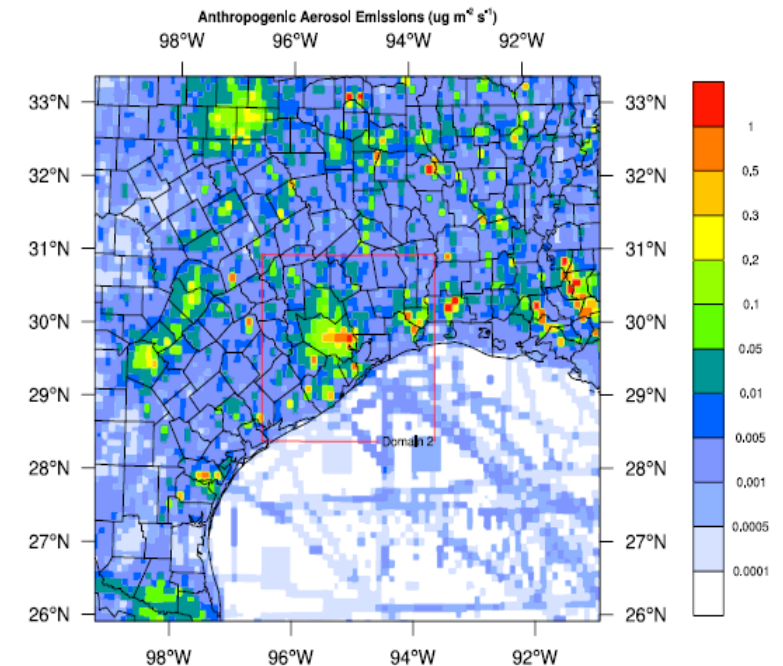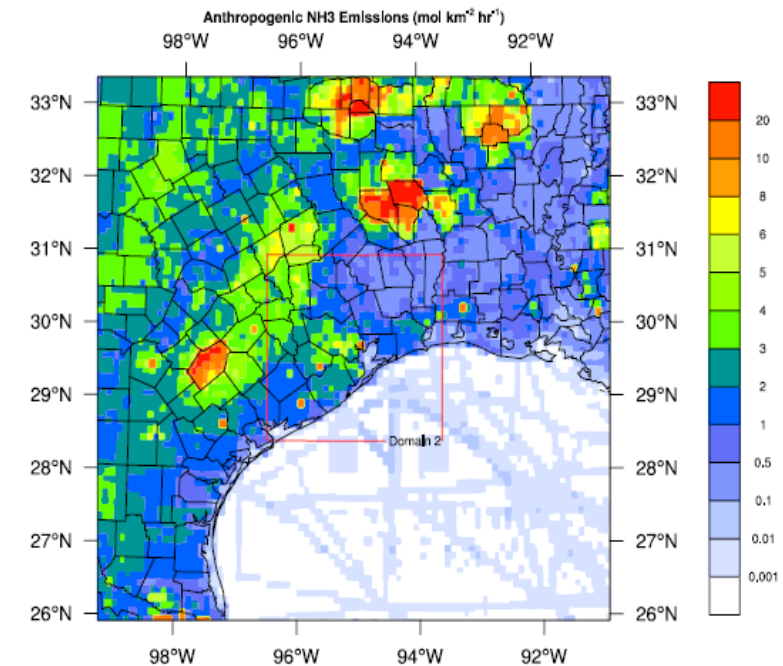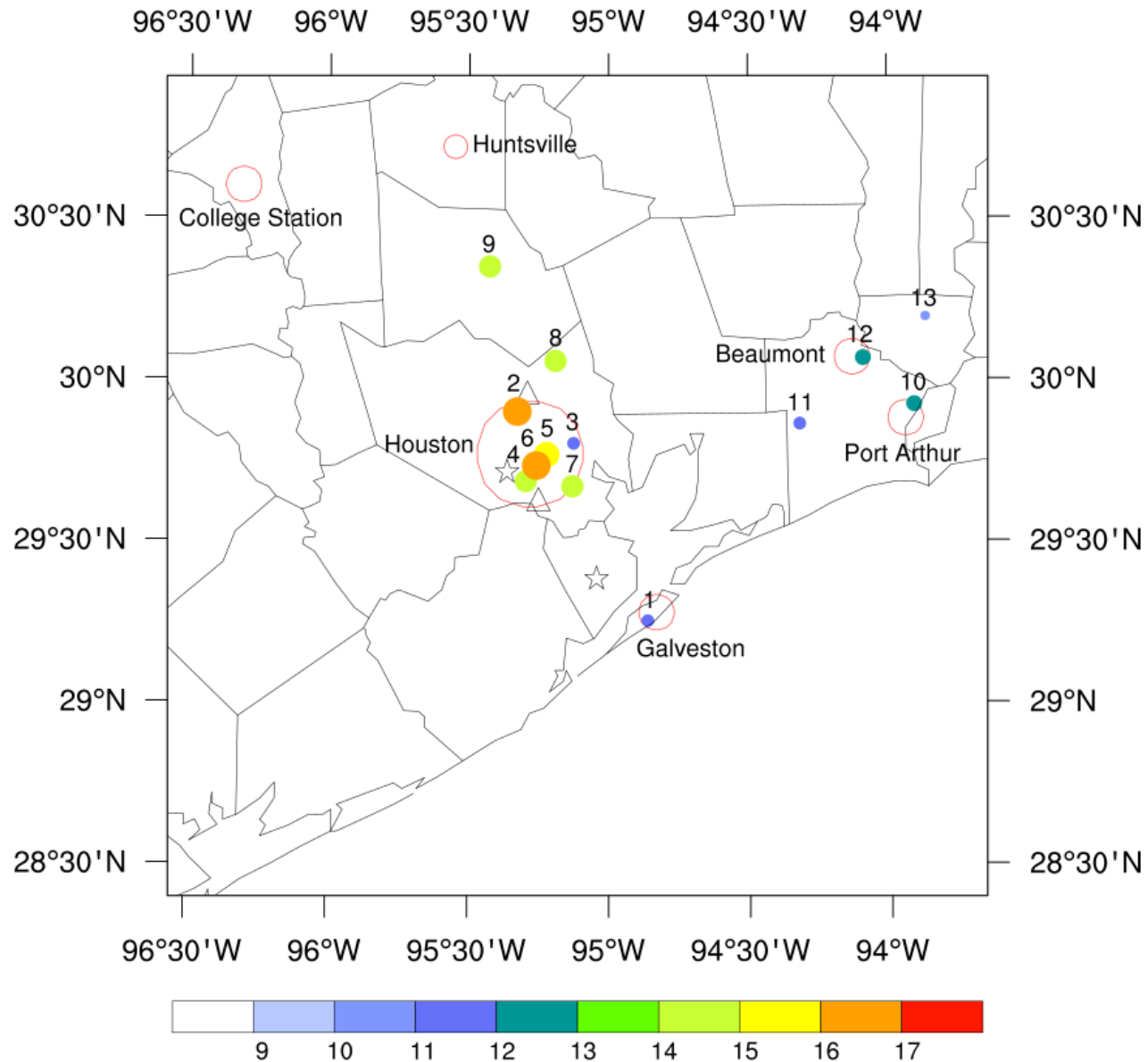
Observations for model evaluation

(16-22 June 2013)

- Colored ● : AQS sites

- Δ: Meteorology sites

- ☆: AERONET sites

- ◯: Major city

AERONET – daily
mean AOD at 500 nm

y = 0.524x + 0.123
r = 0.96
Bias = -0.028
RMSE = 0.058

Modeled AOD at 500 nm

AERONET AOD at 500 nm

UH Coastal Center (-95.04˚, 29.39˚)

Mod. - AOD
Obs. - AOD
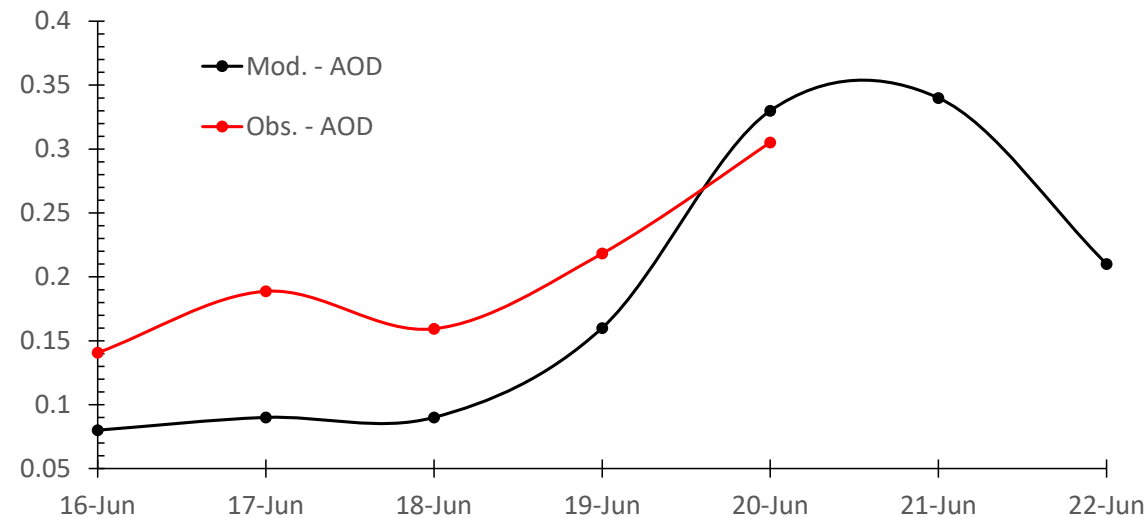
University of Houston (-95.34˚, 29.72˚)

Mod. - AOD
Obs. - AOD

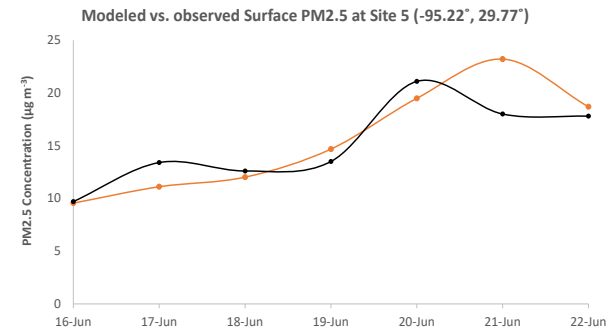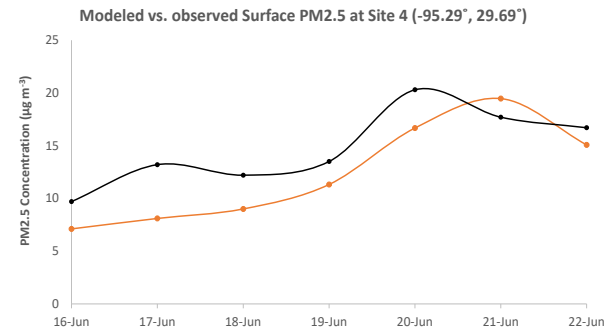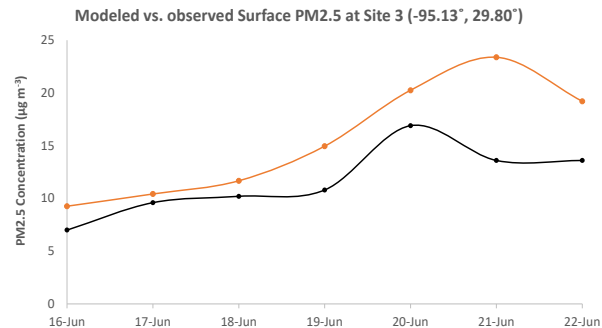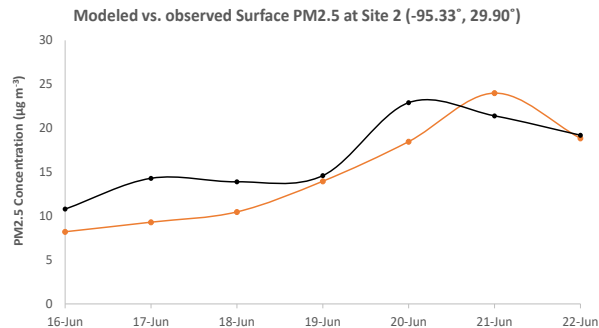Simulated multi-day average aerosol composition at each AQS site
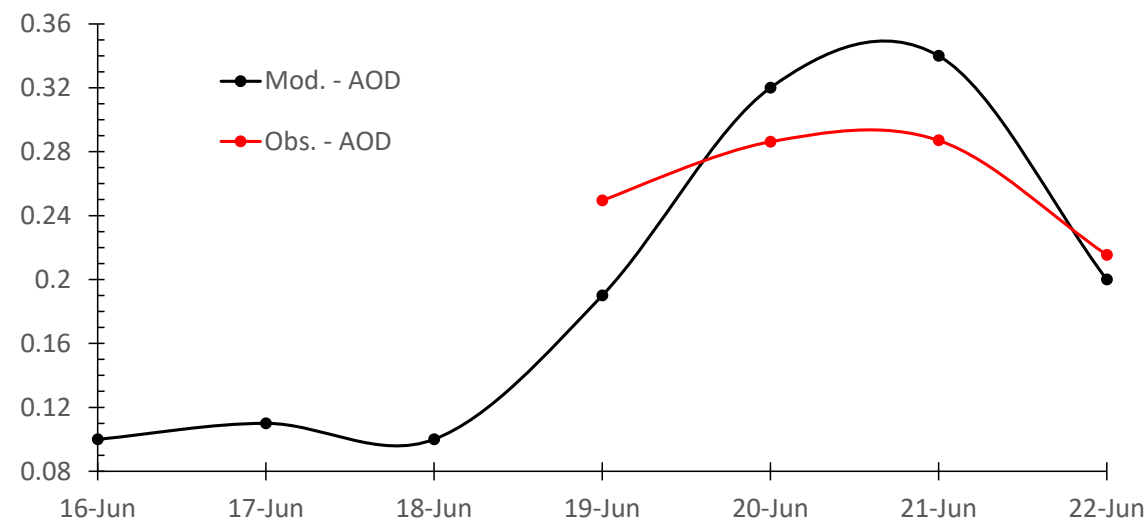
AQS – weekly average 24-hr mean PM2.5 at surface

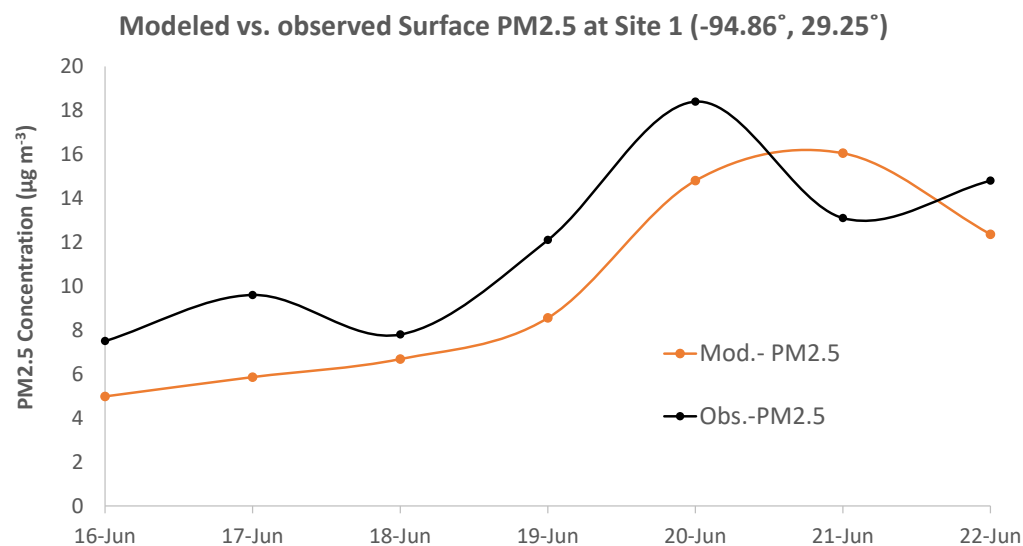Simulated multi-day average aerosol composition at each AQS site
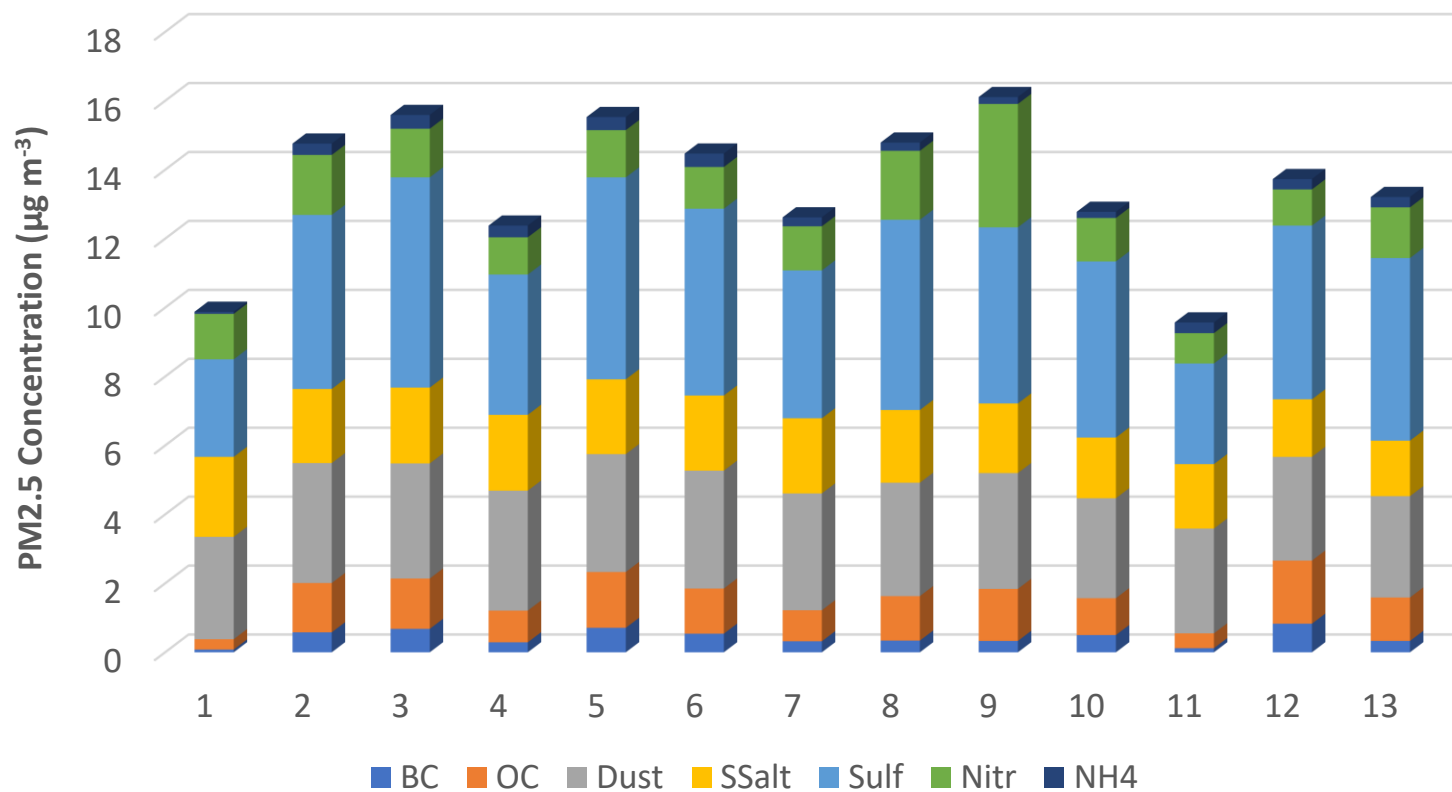
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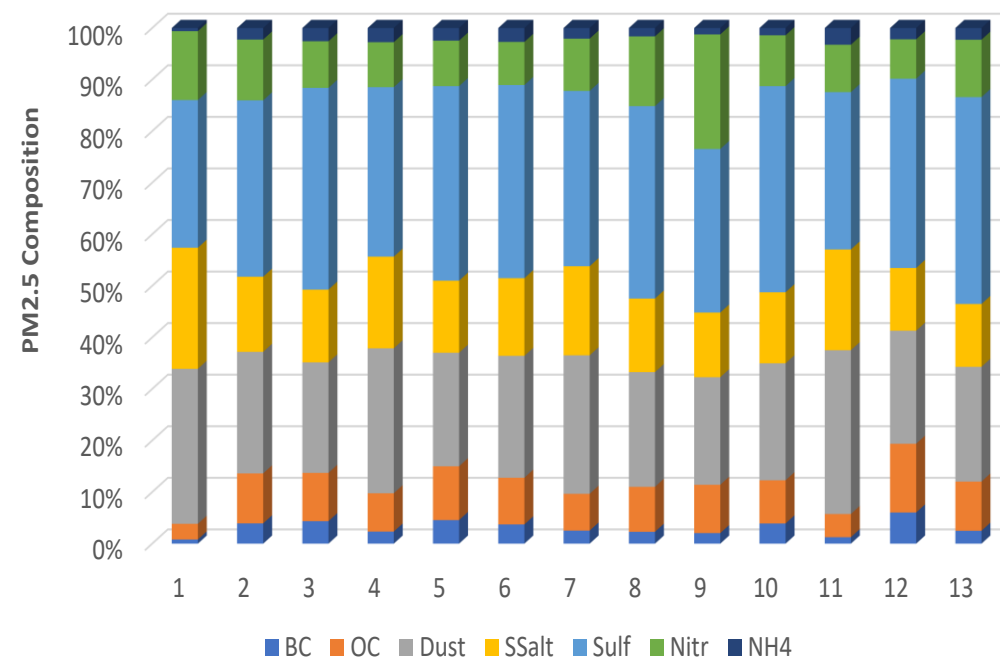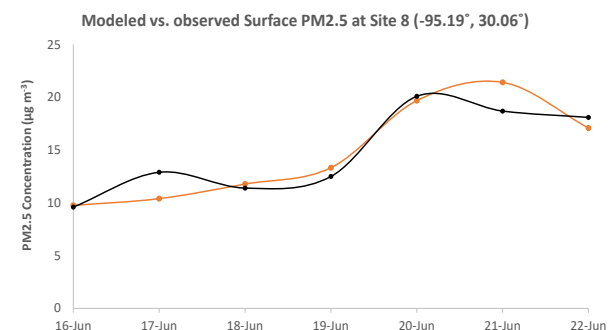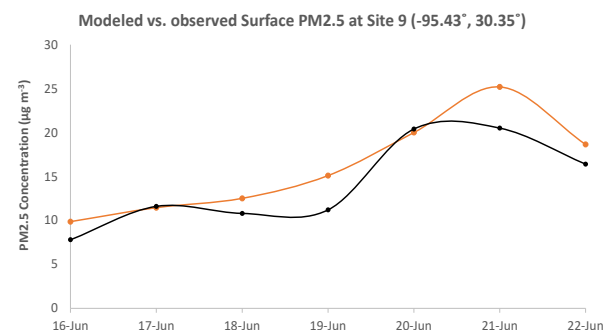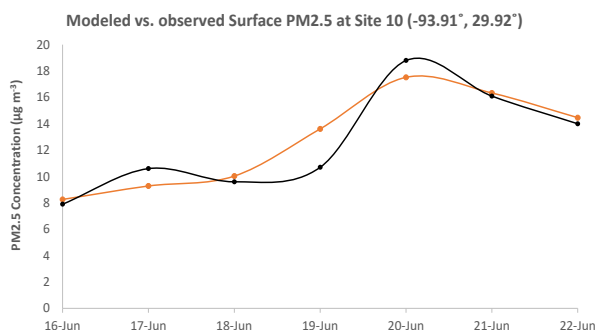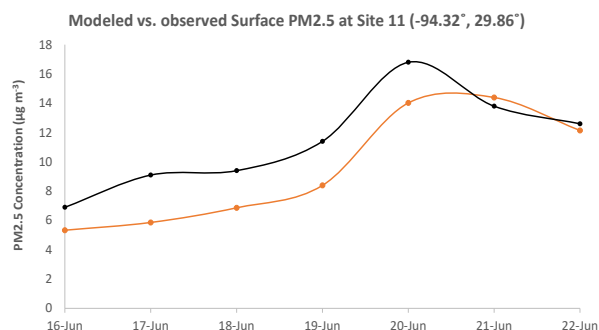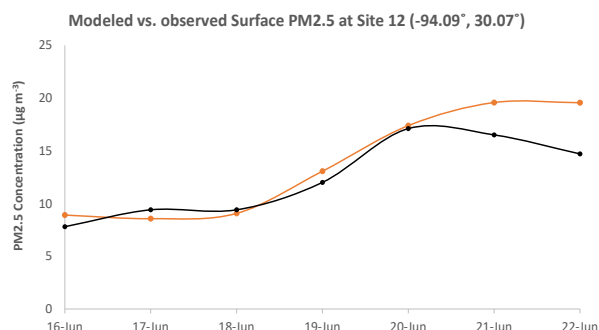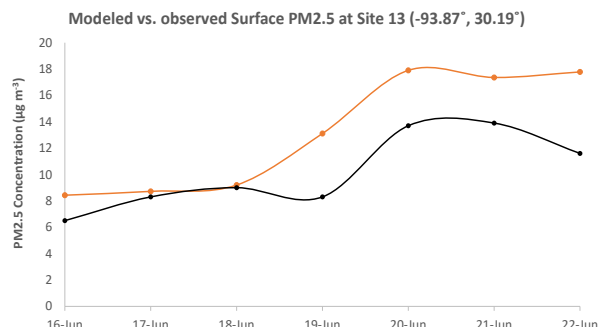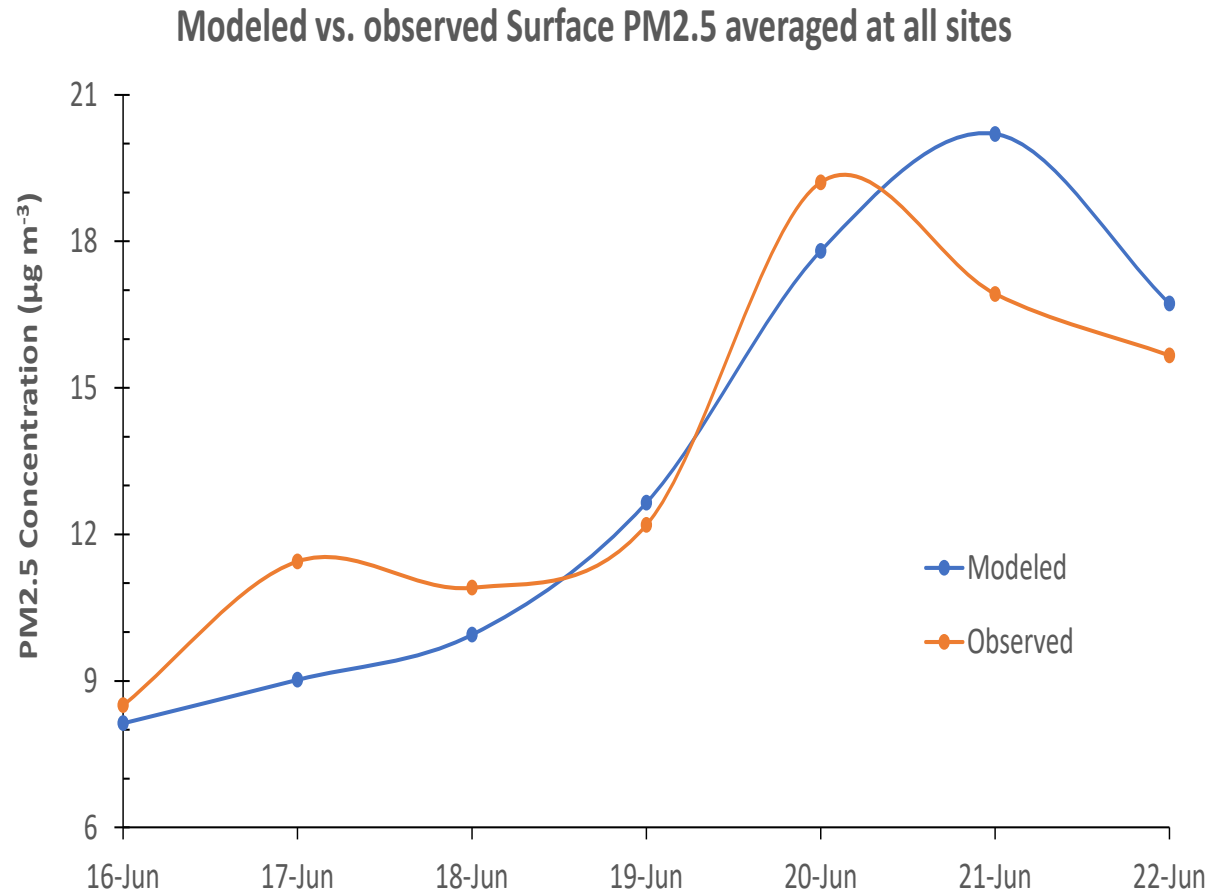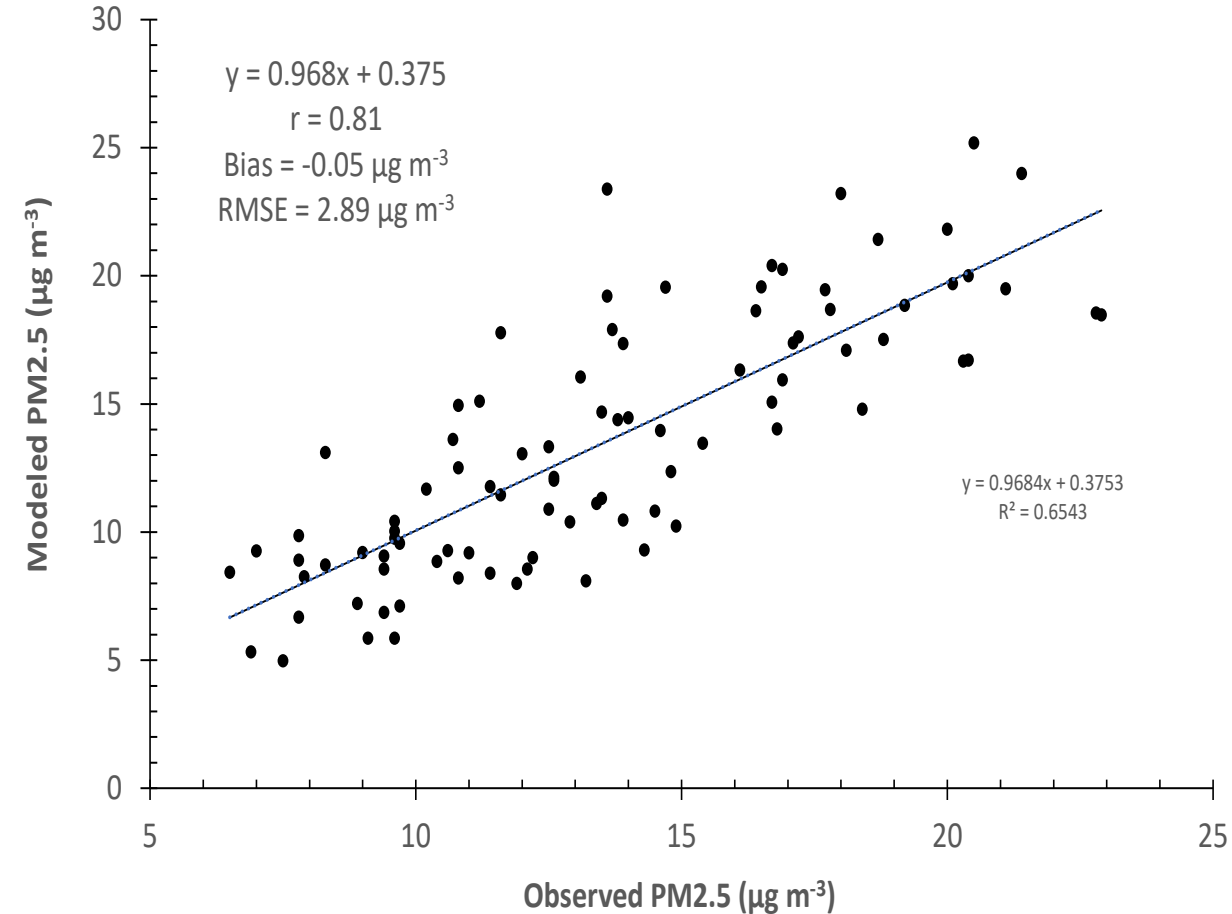
AQS – temporal evolution at each site

AQS – temporal evolution (averaged over all sites)

AQS – regression analysis (incl. all sites)

Modeled vs. observed Surface PM2.5 averaged at all sites

$y = 0.968x + 0.375$
$r = 0.81$
Bias = -0.05 $\mu g\ m^{-3}$
RMSE = 2.89 $\mu g\ m^{-3}$

$y = 0.9684x + 0.3753$
$R^2 = 0.6543$

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Met station

Houston George Bush International Airport (IAH, 29.93N, 95.31W)
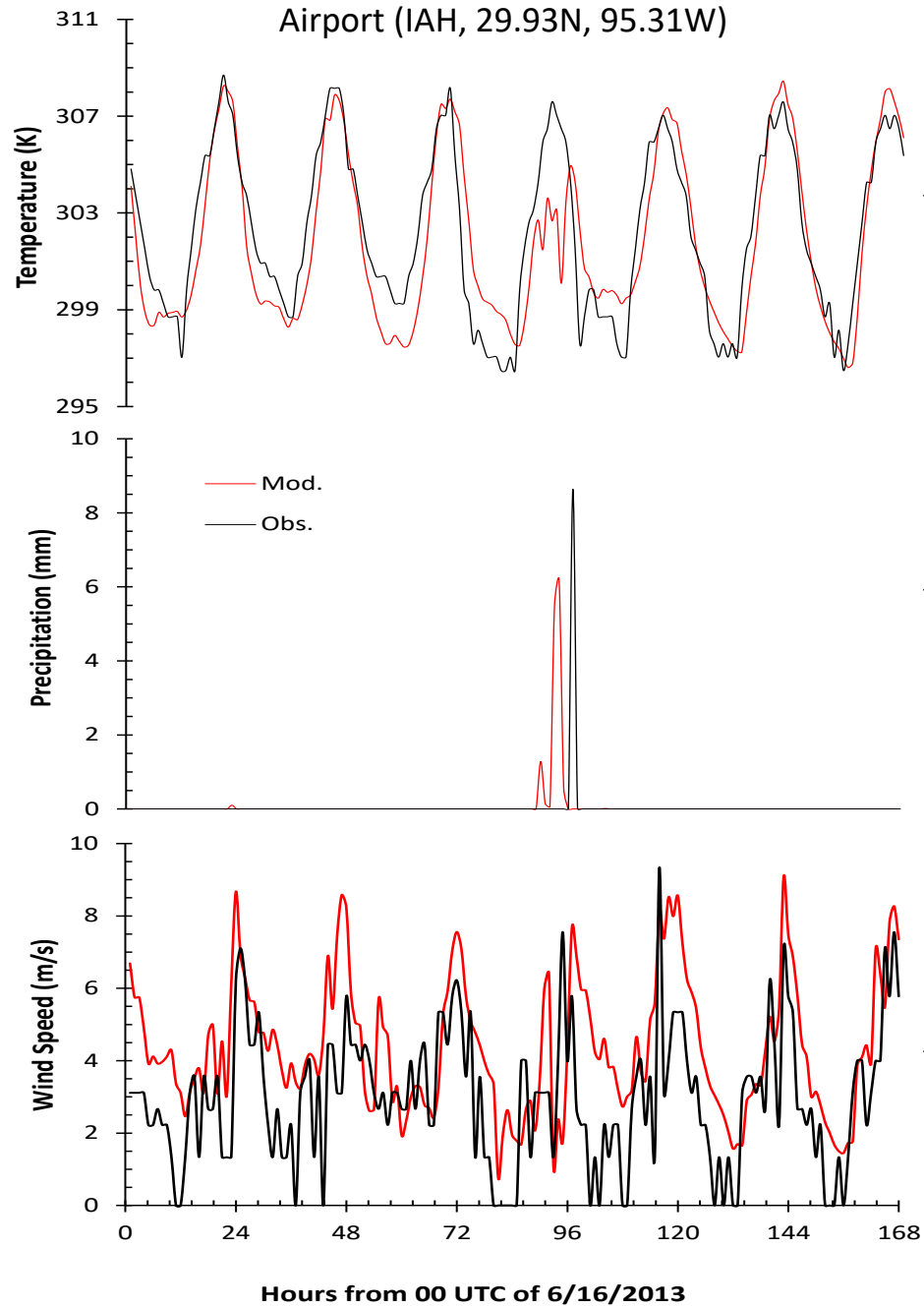
Houston William P. Hobby Airport (HOU, 29.63N, 95.25W)

	IAH		HOU
Bias	-0.40		-0.69
RMSE	1.81		1.57
r	0.87		0.91
Bias	0.03		0.02
RMSE	0.93		0.22
Bias	1.42		1.55
RMSE	2.19		2.20
r	0.60		0.63

Hours from 00 UTC of 6/16/2013
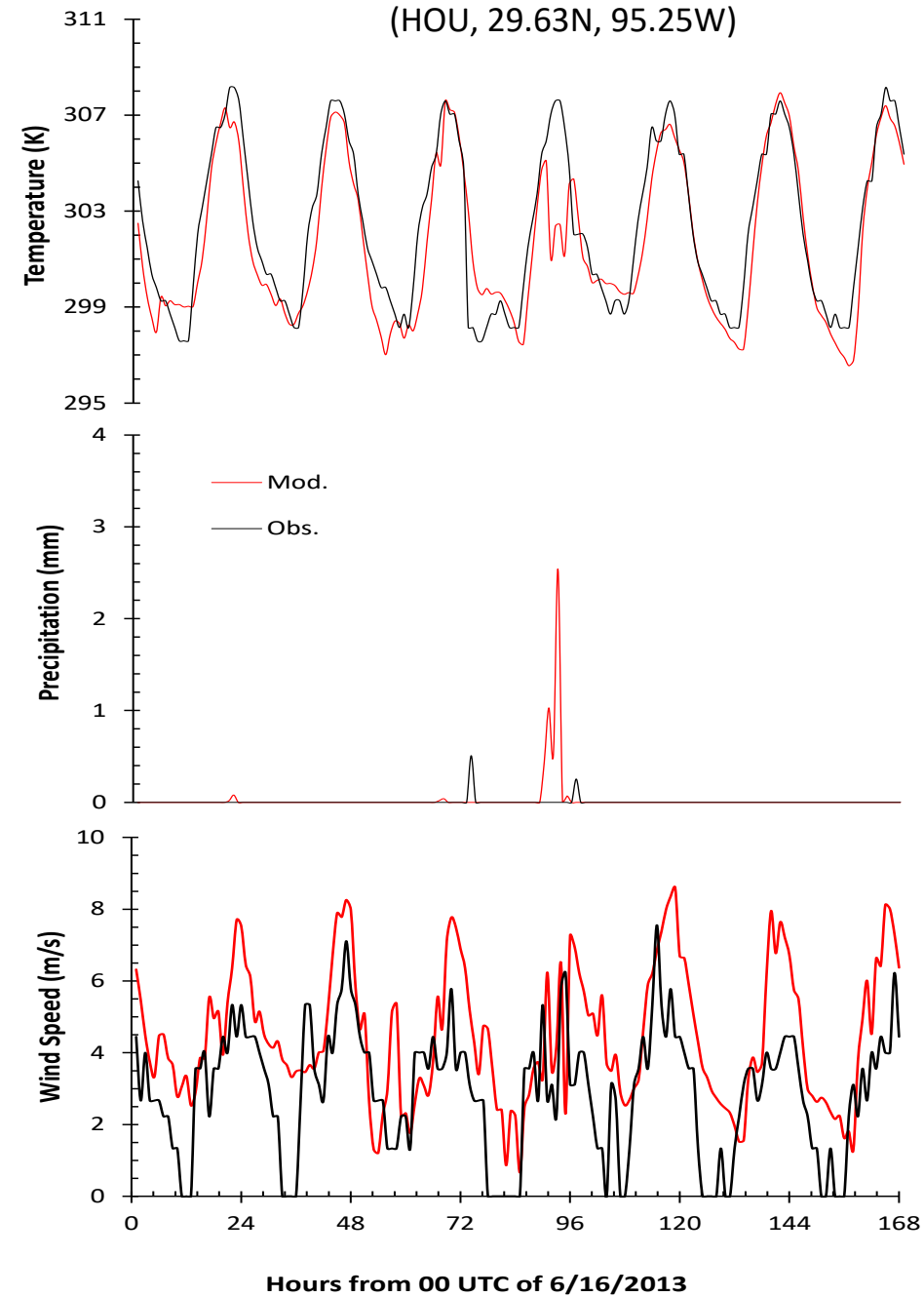
Take-home message

- In support of the emerging GEO-LEO satellite observations of atmospheric composition, NU-WRF's aerosol module has been improved to 1) parameterize SOA, and 2) account for nitrate

- Application of the modified NU-WRF to the Houston metropolitan areas demonstrates the good model skill in reproducing the observed meteorology and aerosol spatiotemporal distribution (PM2.5 and AOD)

- In the future, NU-WRF will be set up over North America (TEMPO) and East Asia (GEMS) to analyze satellite observations and better understand processes that control the spatiotemporal distribution of key atmospheric components

- Questions